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INVESTIGATION OF THE SURFACE PROPERTIES OF HARDENED AND PVD-COATED DIN 115CRV3 STEEL FOR CUTTING TOOLS APPLICATION

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ABSTRACT

The use of cutting tools coated with ceramics is growing every year, and there is a need for high-performance and cheaper tools. In this study, an inexpensive cold work tool steel DIN 115CrV3 was hardened at different temperatures and was coated with physicalvapor deposition (PVD). The results show that the highest hardness value is obtained after quenching at 780°C. The ferrite and cementite phase transformed to martensite with a hardness of 820 HV. The rigid TiN layer (1883 HV) has been found to be thick with lower surface roughness compared with the CrN layer (1792 HV). The corrosion test performed on tools found that CrN coating had lower corrosion potential (−220 mV) than rivals. The findings suggest that ceramic coating was successfully performed on DIN 115CrV3 and tribological performance should be tested.

Keywords: Steel, Cutting tools, Hardness

SERTLEŞTİRİLMİŞ VE PVD KAPLI DIN 115CrV3 ÇELİĞİNİN KESİCİ TAKIM UYGULAMALARI İÇİN YÜZEY ÖZELLİKLERİNİN ARAŞTIRILMASI

ÖZET

Seramik ile kaplanmış kesici takımların kullanılması her yıl artmaktadır ve bu nedenle yüksek performanslı aynı zamanda ucuz kesici takımlara ihtiyaç vardır. Bu çalışmada, ucuz bir soğuk iş takımı olan DIN 115CrV3 çeliği farklı sıcaklıklarda sertleştirilmiş ve fiziksel buhar çöktürme (PVD) ile kaplanmıştır. Sonuçlar, 780 ° C de sertleştirme işlemi sonrası en yüksek sertlik değerinin elde edildiğini göstermektedir. Ferrit ve sementitfazı, sertliği 820 HV olan martenzitfazına dönüşmüştür. Sert olan TiN tabakanın (1883 HV), CrN tabakaya (1792 HV) göre yüzey pürüzlülüğü düşük ve kaplama kalınlığı büyüktür. Uygulanan korozyon testleri sonucunda CrN kaplamanın diğerlerine göre daha düşük korozyon potansiyeline (-220 mV) sahip olduğu bulunmuştur. Bulgular seramiklerin başarıyla DIN 115CrV3 çeliğine kaplandığını ve tribolojik performanslarının incelenmesi gerektiğini göstermektedir.

Anahtar Kelimeler: Çelik, Kesici takımlar, Sertlik

1. Introduction

Nowadays, modern machine cutting toolsused inmachining technology work underhigh mechanical stresses.For example, cuttingat high temperatures needs satisfactory hardness, strength, and toughness properties[1, 2]. Tools that were produced from HSS-steel exhibit a lower wear resistance that limits their tool life [3, 4]. The cost of cutting tools in the manufacturing industry has a large share in total costs. For this reason, cheaper new-type cutting tools are needed to decrease productivity cost and to increase the competitiveness of countries.

Cutting tools made of steelarecheap and are the most widely usedmaterialsin the industry. These are oflow quality and low resistance, and they arereadily available and inexpensive tools.The cutting performance of these steels can be increased by appropriate heat treatment. Quenching treatment changes the microstructure of steel from austenite to martensite. This structure is the hardest knownfor steel, with a hardness of 62–65HRC[5-8].Besides, surface coating methods are used to develop appropriate cutting tools with higher mechanical properties. Hard thin film coating improves the wear resistance and tribological characteristics of the tip of the tool materials. Particularly, cutting tools containing nitride and carbide hard coatings such as TiN, TiCN [9], TiC, TiAlN, CrN, and AlCr [10-13] are widely investigated. Kadirgama and his coworker [14] have coated Hastelloy C-22HS with physicalvapor deposition, or PVD (TiN, TiCN, and TiAlN) and CVD (TiN, TiCN, TiAlN, and Al2O3). They found that in terms of cutting tool life, PVD is better than CVD, especially coating with TiAlN. The wear properties of AISI 1070 steel coated with TiN and CrN were analyzed by Cakan and his coworkers, and they found that TiN-coated tools demonstrate better wear resistance than CrN-coated tools[15]. Wear resistance depends on the surface modification technique used[16-18]. Fine-grained microstructure and high surface hardness are some advantages of the PVD coating method over other methods [19-22].

High wear resistance of TiN coatingcan be appliedin many material types; it increases tool life,improves material handling, and suppliesa structure that has the ability to be usedat faster speeds [23, 24]. CrN coating, compared with PVD, had lower hardness; however,it had ahigh chemical resistance. During cutting, it partiallysticks on the workpiece and on anticorrosion materials [25, 26]. In addition, it is well defined in the literature that CrN coating had better corrosion resistance because of its dense structure [27].

In this study,the possible use of low-alloyedDIN 115CrV3steel as a cutting tool was investigated. This alloyisattr active because of its good mechanical properties and its cheapness. This paper mainly focuses on the mechanical and surface properties of hardened and PVD-coated DIN 115CrV3 tools.

2. Experimental Procedure

2.1 . Materials and Sample Preparation

The alloy materialhas been obtained fromthe marketin the form of a rod. Then the rods were cut longitudinally into several pieces measuring 10 cm,and they were machined to obtain 1 × 1 × 10 cm cutting pieces and to give them the form of a cutting tool.

2.2 . Heat Treatment

Different heat treatment applications were carried out to the cutting tools in order to obtain a harder tip without stress. The heat treatment was realized with furnace MF120. The annealing temperatures were 760°C, 780°C, and 800°C, and the rapid cooling of specimens wasrealized in water at an ambient temperature. In the literature, the heat treatment of DIN 115CrV3 steel is well defined. However, for the calibration of the furnace, it was necessary to test different temperatures. Heat treatment was carried out as follows: The tools were heated until the desired temperature was achieved, the chosen annealing time for every piece was 30 minutes, and then only the tips of the pieces were quenched for 1–2 seconds in cold water rapidly, and after that, the rest were sunk. Afterward, the specimens were tempered at 150°C for 30 minutes to remove their residual stress, which occurs after rapid cooling.

2.3. Ceramic Coating

TiN and CrN ceramic coatings were performed by PVD machine Novatec31 arc was used for this purpose. The surfaces of the cutting tools before coating operations were ultrasonically cleaned with basic (alkaline) cleaners. Afterward, they were subjected to high-purity nitrogen gas in a deposition chamber. The main material, 99.9wt% purity titanium or chromium, was coated by generating arc ion bombardment on the surface of the cutting tools.

2.4. Corrosion Test

The corrosion test was performed with SP-50 (BioLogic) potensiostat. ASTM standard G5-94 [28] was used to perform the potentiodynamic tests. Potentiodynamic curves were traced at a scanning rate of 1 mV/s on the polished surfaces. All of the potentials are given with respect to a saturated Ag/AgCl: Ag/AgCl/KCl(sat. in H2O), 0.197V vs. SHE. After immersion in the experimental corrosive media 1% NaCl, the test began within one minute, and a potential range of 1000 mV was scanned. At least three tests were performed, and the reproducibility of corrosion rate was of the order ±5%–10%.

2.5. Surface Analysis

The microstructure and elemental analysis of cutting tools were analyzed with a scanning electron microscope (SEM)(LEO 1430 VP) and electron dispersive spectroscopy (EDS). Atomic force microscopy (AFM) was performed to obtain topographic images of the surfaces of the materials and surface roughness. For this purpose, noncontact mode, intermediate end MSC-16, frequency of 1 Hz, and an image resolution of 300 dpi were selected as parameters. The phase structure of the material was determined with the x-ray diffractometer (XRD)(Rigaku MiniFlex). A scan range between 10° and 70° using Ni-filtered Cu K sample surface (α) radiation was used at a scan speed of 2°C/min, and the step of 0.01° was selected. Microhardness measurements were made with the device SHIMADZU, the minimum load 10 g was chosen during the hardness measurement, and the load application time was 15 seconds.

3. Results and Discussion

3.1. Hardness of Tools

The most favorable conditions for the operation of cutting tools should include specific proportions of the alloy elements in the structure. Particularly, the presence of alloy elements such as Cr, V, W, Mo, and Co is important for tool life. DIN 115CrV3 is a low-alloyedsteel tool with high abrasion resistance. Besides, it has good mechanical properties and carbide-forming elements that increase tool life.

Hardness values were measured after heat treatment and coating (figure 1). The untreated sample was soft and had a hardness of 372 HV. After quenching temperatures of 760°C, 780°C, and 800°C,as expected, the hardness of steels increased remarkably. At 760°C, the hardness reached 440 HV. Increasing the temperature of quenching up to 780°C resulted in double hardness (820 HV) compared with untreated cutting tools. At a higher quenching temperature, 800°C, a small decrease of hardness is observed compared withquenching at 780°C. Moreover, quenching at 850°C resulted in cracks observed on the surface of the tools. This is mainly due to higher quantity formation of brittle martensitic phase on the surface of hardend sample at 850^{o}C compared to 780^{o}C.

The hardened tools at 780°C were coated with PVD according to the findings above. Then the microhardness values of PVD-coated cutting tools were measured and are presented infigure 1. The hardness values are 1883 HVand 1792 HV, respectively, for an applied load of 10 g. According to the literature, the microhardness of TiN and CrN are 2200 HV and 2000 HV, respectively, when using an applied load lower than 10 g [1, 16, 29]. The difference of the result is to the limit of the microhardness device used; the minimum load applied was 10 g and the thickness of the coatings.

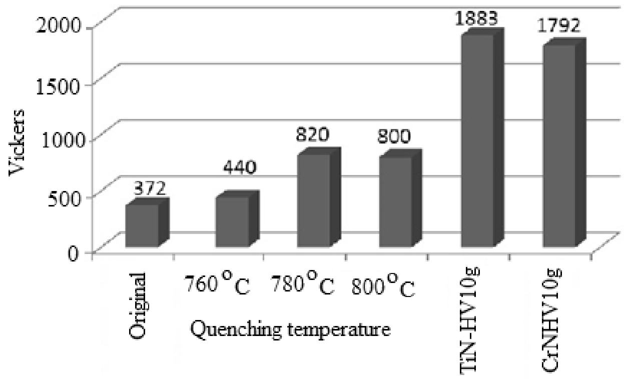

Figure 1. The hardness measurement of DIN 115CrV3 cutting tools after heat treatment and PVD coating.

3.2. The Microstructure Analysis of Uncoated Tools

Figures 2 to4 show SEM images of cutting tools before and after heat treatment. The untreated toolsare composed of ferrite and cementite phases (figure 2). Pearlite is distributed in the ferrite matrix in nodular form. On diffraction pattern 2, intensive main peaks appear at 2Ө =43.26° and 2Ө =64° (figure 2). These peaks correspond to the α-ferrite phase, while smaller peaks fit to the Fe_3C phase.

The first point on figure 2A corresponds to the ferrite phase (white color), respectively. In this phase,the element C is higher, while V is lower compared withthe two other points. The second point (black area) has the same chemical composition, but Mn and Cr are higher compared with points 1 and 3. The third point shows the chemical analysis of grain boundary. It shows the formation of metal carbide. After quenching at 780°C, the microstructure changed completely,as shown in figure 3, and according to the microstructure, some of the regions highlight the presence of pits. The XRD analysis of the quenched tools at 780°C confirm martensite phase (a novel peak appeared at 2Ө = 28° compared with untreated alloy) with austenite phase. The martensitic structure analysis is presented in table 2. The white spherical phase is mainly composed of C, Mn, Cr, and V carbides (point 1, figure 3A). For the black phase, a similar chemical composition is obtained; however, Cr and V were found to be higher compared with point 1.

When quenching temperature is increased to 800°C, the quantity of nodular phase is increased and deep pits disappear on the surface compared with quenching at 780°C (figure 4).

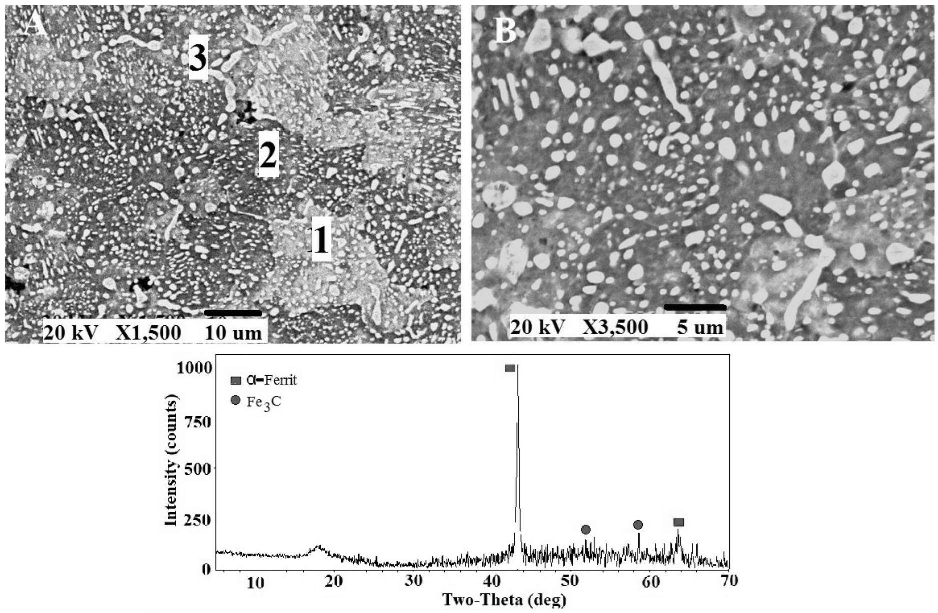

Figure 2.SEM images of untreated tools with magnifications of (A) ×1500 and (B) ×3500 and XRD analysis of the surface (below).

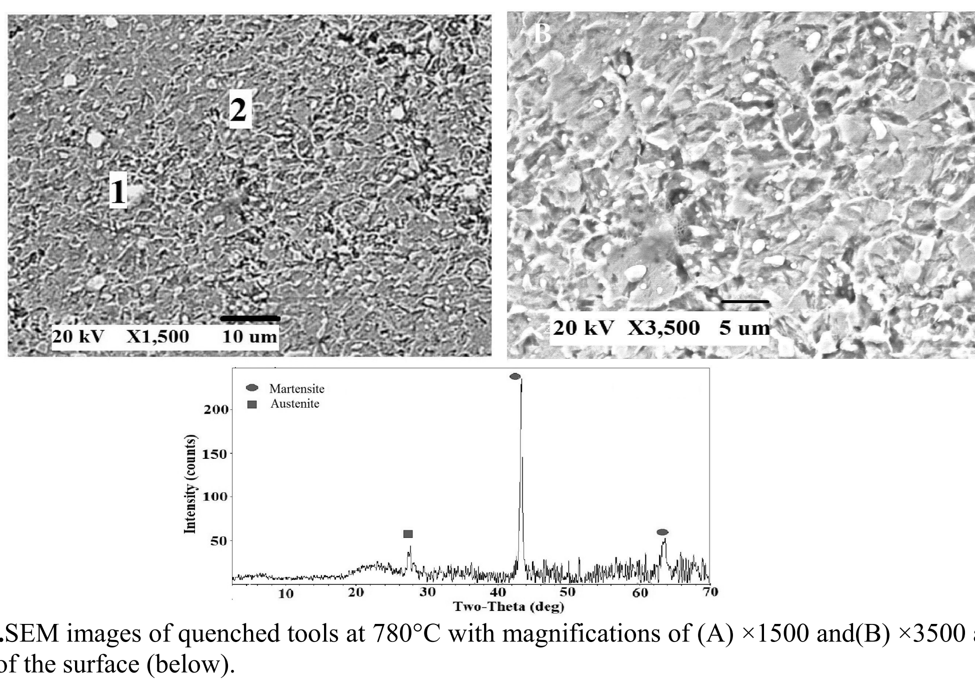

Figure 3.SEM images of quenched tools at 780°C with magnifications of (A) ×1500 and(B) ×3500 and XRD analysis of the surface (below).

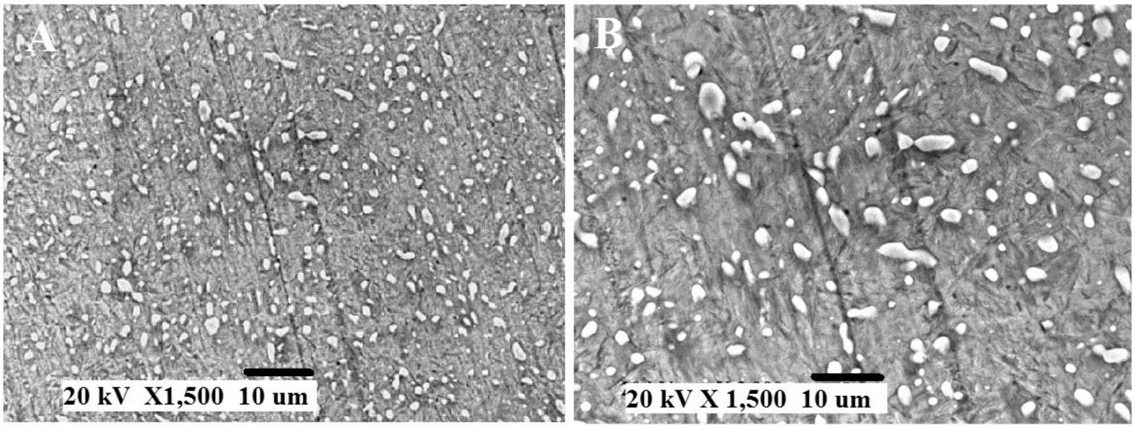

Figure 4.SEM images of quenched tools at 800°C with magnifications of (A) ×1500 and (B) ×3500.

Table 1.EDS analysis of surface on figure 2(represented as % wt).

Point	Fe	Mn	C	Cr	V
1	90,26	4,47	1,51	3,39	0,13
2	90,64	3,92	1,06	3,63	0,16
3	91,69	3,38	0,88	3,47	0,25

Table 2.EDS analysis of surface on figure 3(represented as % wt).

Point	Fe	Mn	C	Cr	V	O
1	72,11	4,72	1,40	0,55	0,23	20,10
2	91,24	2,36	1,25	0,62	0,25	—

3.3. The Microstructure Analysis of Coated Tools

Figure 5 shows the cross-sectional view of TiN-coated tools. In general, the coating appears well adhered and distributed without cracks on the surface of the main material. The average coating thickness was 2.76 µm. This thickness corresponds substantially to the results obtained by other researchers in the literature [6, 11, 22]. Generally, for TiN coatings, as it is known, the thickness ranges from 1 to 5 µm. Two main phases, TiN and Ti_2N, were found after XRD analysis (figure 5). The results of the EDS analysis of the five points on the SEM picture are presented in table 3. Point 1 corresponds to the coating layer structure that involvesthe elements Ti, N, and C. At the interlayer (point 2), the coating of the elements Ti, N, and C were still observed. Points 3,4, and 5 present the EDS analysis of the main material. Point 3 had the highest amount of the element Cr compared with points 4 and 5. This point corresponds to the rounded phase. The surface roughness of the TiN coating was found to be Ra =56.1nm.Figure 6 shows that the surface appears flat with some island after scanning with AFM.

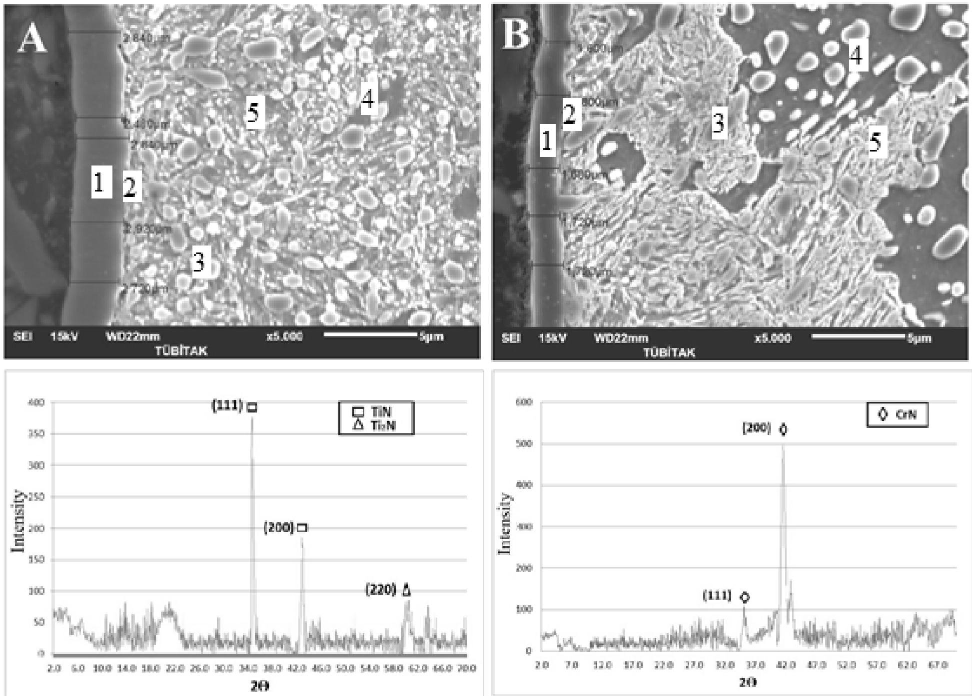

Figure 5. Crosssection of (A) TiN and (B) CrN coating and XRD analysis of the surfaces (below).

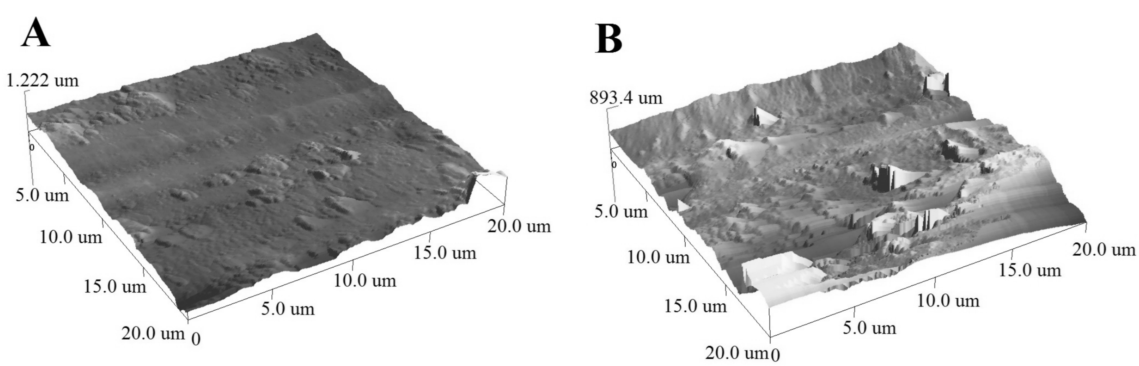

Figure 6. The AFM image of TiN-coated cutting tools,(A) two-dimensional image and(B) three-dimensional image.

CrN coatings provide a goodadhesion to the materialaside from high hardness and high temperature resistance. The crosssection of the CrN-coated cutting toolsis shown in figure5. As observed, the CrN layer coating is well adhered with no cracks and delamination. The thickness of the CrN coating was found to be approximately 1.70 µm. According to the TiN coating, CrN coating hickness isless than1.06 µm. The formation of CrN is realized at the directions of 111 and200 (figure 5). Five important points were analyzedin figure 5B. The first point corresponds to the CrN coating. As expected, the elements Cr,N, and C were found in the coating. The coating layer includes CrN and at least somechromiumcarbide ($Cr_7C_3$and$Cr_{23}C_6$). It means that Cr residues were connected as chromium carbide (table 4). At the interlayer, a similar chemical composition is found (point 2). Points 3,4, and 5 are composed principally of Fe and C.

Table 3.EDS analysis of the crosssection of TiN surface on figure 5A (represented as % wt).

Point	Ti Kα	N Kα	C Kα	Fe Kα	Cr Kα
1	78,51	12,59	8,90	-	-
2	76,86	13,64	9,5	-	-
3	-	-	12,91	85,98	1,11
4	-	-	11,17	87,88	0,95
5	-	-	13,44	85,91	0,65

Table 4.EDS analysis of the crosssection of CrN surface on figure 5B (represented as % wt).

Point	Cr	N	C	Fe
1	69,95	18,12	11,93	-
2	71,51	17,85	10,64	-
3	-	-	10,99	89,01
4	-	-	12,78	87,22
5	-	-	13,64	86,36

The average surface roughness measured for CrN surface was Ra =66.6nm. This valueis higher than that of TiN coating. The main reason forthis is the presence of sharp peak on the surface of CrN coating. This result can also affect negatively the wearand cutting performance oftools.

3.4. Corrosion Resistance of Tools

The corrosion resistance of cutting tools was tested using1% NaCl solution (figure 7). In general, treated cutting tools had much better corrosion resistance than untreated cutting tools; untreated steel had higher corrosion after TiN coating, hardened steel (martensite), and CrN coating. CrN coating (−220 mV) had higher corrosion resistance compared with untreated steel (−700,3mV),which had the worst corrosion resistance. In addition, untreated steel, TiN coating, and hardened steel show a small passivation at −400 mV, −300 mV, and −250 mV, respectively. This passivation means a formation of oxide film that blocks the corrosion attack of choloride ions for a while.

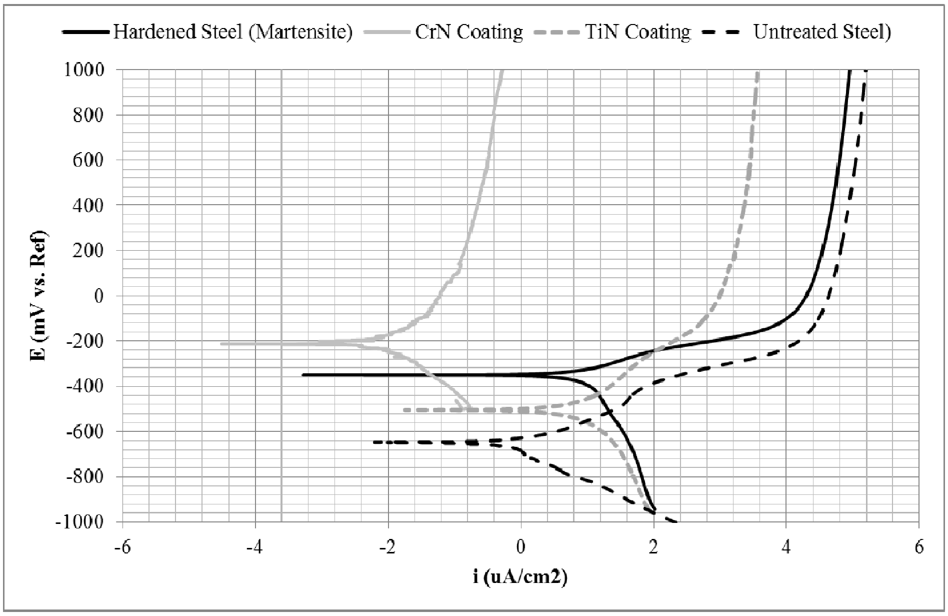

Figure 7. The polarization curves of cutting tools in 1% NaCl solution with a scan of 1 mV/s.

4. Conclusions

In this study, the use of DIN 115CrV3 steel alloy as a cutting tool was investigated. The results show that heat treatment and PVD coating increased the hardness and the corrosion resistance of tools.The following conclusion can be drawn:

1. The quenching at 780°Cincreased the hardnessof the tools about wotimes compared with untreated tools.I ncreasing the quenching temperature leads to internal stress, and finally, cracks occur.

2. PVD coating was successfully realized on tools; TiN coating was thicker, and the surface roughness was less compared with the CrN coating.

3. CrN-coated cutting tools showed better corrosion resistance followed by hardened steel than TiN-coated tools.

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